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Chapter 11. Precipitation Enhancement

Precipitation enhancement, commonly called "cloud seeding," artificially stimulates clouds to produce more rainfall or snowfall than they would produce naturally. Cloud seeding injects substances into the clouds that enable snowflakes and raindrops to form more easily. Precipitation enhancement is the one form of weather modification done in California. Forms conducted in other states include hail suppression (reducing the formation of large, damaging hailstones) and fog dispersal (when fog is below freezing temperature). (There are some unconfirmed reports of hail suppression attempts in the San Joaquin Valley, using hail cannons, but the scientific basis for this method is dubious.)

Winter orographic cloud seeding (cloud seeding where wind blows over a mountain range, thereby causing clouds and rain or snow by lifting the air) has been practiced in California since the early 1950s. Most of the projects are along the central and southern Sierra Nevada, with some in the Coast Ranges. The projects generally use silver iodide as the active seeding agent, supplemented by dry ice if aerial seeding is done. Silver iodide can be applied from ground generators or from airplanes. Occasionally, other agents, such as liquid propane, have been used. In recent years, some projects have been trying hygroscopic materials (substances that take up water from the air) as supplemental seeding agents. Figure 11-1 shows rain and snow enhancement programs that were considered operational in 2011. Most rain and snow enhancement projects are long-term projects that operate in all or most years. A few, such as Monterey County's project, only ran in one or two seasons. Historically, the number of operating projects has increased during droughts, up to 20 projects in 1991, but has leveled off at about a dozen in wet or normal water years. Most of the agencies or districts doing precipitation enhancement projects suspend operations during very wet years once enough snow has accumulated to meet their water needs.

PLACEHOLDER Figure 11-1 Weather Modification Project Areas in 2011

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

State requirements for sponsors of weather modification projects consist of filing a notice of intent (NOI) initially, and every five years after for continuing projects; some record keeping by operators; and annual or biennial reports to the California Department of Water Resources (DWR). The information to include in the NOI can be obtained from DWR. In addition, sponsors need to comply with the California Environmental Quality Act and should send annual letter notices to the board of supervisors within affected counties and to DWR. The National Oceanic and Atmospheric Administration (NOAA) also requires activity reports, which give the number of days and hours of operation and the amounts of seeding material applied.

Policy statements by both the American Meteorological Society in 1998 and the World Meteorological Organization in 2007 support the effectiveness of winter orographic cloud seeding projects, although they acknowledge that results may be uncertain because of the high degree of background variability of weather. A more detailed treatment of weather modification capabilities, position statements, and the status of the discipline is in *Guidelines for Cloud Seeding to Augment Precipitation* (American Society of Civil Engineers 2006).

An editorial in the international journal Nature in June 2008 advocated for a renewed push for scientific research into weather modification activities. For years, weather modification supporters faced a perceived negative bias in the scientific community because early increase claims were exaggerated. The editorial in a widely respected scientific journal may mark a turn in opinion. Massive weather modification efforts in China for the 2008 Olympics did not go unnoticed in the press also that year. Also, in 2011, evaluations of a five-year experimental program in the Snowy Mountains of southeastern Australia confirmed a significant precipitation increase in seeded storms.

Since 2009, the last time the California Water Plan was updated, there have not been many new developments in weather modification in California. Most of the projects have continued to operate as before. The demise of one of the oldest commercial operators in the field, Atmospherics Inc. in Fresno, led to some changes as sponsors had to find a substitute operator. A new firm, RHS Consulting Ltd., entered the field and in 2011 was conducting operations in the San Joaquin, Kaweah, and Kern river watersheds in the southern Sierra Nevada mountains.

Pacific Gas and Electric Co. (PG&E) had planned a new project on the Pit and McCloud rivers in Northern California on the headwaters of Shasta Lake, but this has been dropped to avoid further controversies in light of criticism of PG&E after one of its gas pipelines exploded in San Bruno in 2010. This would have been one of the more productive precipitation enhancement projects in California because the region gets frequent storms and has the ability to take advantage of natural storage by increasing precipitation recharge of the large volcanic aquifers that feed the Pit and McCloud rivers year round (also increasing hydroelectric power production on these rivers). Potential yield could have been as much as 200,000 acre-feet (af) of precipitation. Much of the added precipitation would have gone into recharging the large volcanic aquifer, which supplies the year-round springs in the region.

Another area of interest to California is the Colorado River basin, where a lengthy drought has caused the seven states of that basin — Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming — to look at all potential options. The best hope of augmenting Colorado River water supply is wintertime cloud seeding in the headwater states of Colorado, Utah, and Wyoming. There are already many seeding programs in place. However, the basin states have agreed to work together in a program for implementing new programs and to designate new areas for seeding and possibly longer seasons of operation for existing projects. There were 15 projects already operating in the Upper Basin; there may be potential for up to 15 more in the region, including four in Arizona. From a 2006 study (Griffith and Solak 2006) by North American Weather Consultants, which does weather modification, the combined potential yield of the new programs could be 800,000 af per year on average. This is based on a 10-percent increase in precipitation. Additional amounts could be obtained by augmenting the existing programs, primarily by funding a longer season of operation. As a start, the Lower Basin states added about $390,000 per year in the three years from 2010 through 2012 to enhance Upper Basin cloud seeding efforts.

More research in weather modification is desirable. The kind of research needed and the equipment needed are beyond the ability and funding of independent project sponsors, although much can be gained from piggybacking research onto existing programs. To this end, legislation was introduced in the 110th Congress by Sen. Kay Bailey Hutchison of Texas and then-Rep. Mark Udall of Colorado for federal funding of weather modification research and to increase the effectiveness of existing programs through applied research. This federal research funding effort was unsuccessful.

In California, proposals have been made to the California Energy Commission's (CEC's) Electric Program Investment Charge program (formerly named the Public Interest Energy Research Program [PIER Program]) for additional research into cloud seeding to evaluate the effectiveness of existing programs in the state and optimize their effectiveness. Justification would be the potential impact on hydroelectric energy production. This approach would survey the latest scientific advances in cloud physics, remote sensing, atmospheric science, seeding technologies, and evaluating strategies and would recommend the best course of action to maximize the contribution of operational cloud seeding programs to California's water and energy supplies. Researchers could also study the potential effect of climate change and atmospheric pollution on seeding practices and capabilities. DWR recommends that the Electric Program Investment Charge program include and fund research on cloud seeding in its activities.

The State of Wyoming has undertaken a major weather modification research program, which is now in its seventh year (it began in 2006). The objective is to evaluate, with help from the scientists at the National Center for Atmospheric Research (NCAR), the potential for increased snowpack in the Sierra Madre and Medicine Bow Mountains of southern Wyoming with a randomized experimental design. Some storms are seeded, and some are left unseeded, with extensive measurements of moisture tracking in the air and of results on the ground. The program will need another couple of years after the current one to gain the 120 to 150 cases needed to detect with statistical confidence a positive increase in snowpack due to seeding.

Progress in confirming snowfall enhancement has been made in the Snowy Mountains of Australia. A recent scientific paper by Manton and Warren (2011) shows a 14-percent increase in precipitation when comparing seeded and unseeded experimental units from 2005 through 2009 during the passage of winter cold fronts.

Potential Benefits

In California, all precipitation enhancement projects are intended to increase water supply or hydroelectric power. The amounts of water produced are difficult to determine, but estimates range from a 2-percent to 15-percent increase in annual precipitation or runoff. A National Research Council (NRC) 2003 report on weather modification had limited material on winter orographic cloud seeding, such as is practiced in California and other western states. However, the report did seem to concur that there is considerable evidence that winter orographic weather modification works, up to a 10-percent increase. A 2012 study by the Utah Department of Natural Resources (updating a 2005 study through the 2010 season) showed an average increase in April 1 snowpack water content ranging from 3 percent to 15 percent from a group of projects that had been operating from seven years (high Uinta Mountains) to 32 years (central/southern Utah). The overall estimated annual runoff increase for Utah was about 180,000 acre-feet, or about 6 percent for the study areas. Estimated costs in 2010 were $2.27 per acre-foot (af) from these ground seeding programs.

Actual increases in annual runoff are probably less in California than in Utah. A new estimate made for Update 2013 by DWR staff is that the combined California precipitation enhancement projects, on average, generate about 400,000 af of runoff annually, which would be an average of about a 4-percent increase in runoff.

Accepting the PG&E estimate for the formerly proposed Pit River-McCloud River cloud seeding project of 200,000 af for that region (which is one of the most favorable areas for cloud seeding because of more frequent storms and generally colder weather conditions than other parts of the state tend to have), another 200,000 to 300,000 acre-feet per year (af/yr.) may be available in other areas. Thus, a reasonable state estimated total could average 400,000 af/yr. Many of the other best prospects are in the Sacramento River basin, in watersheds that are not seeded now. The North Lahontan and South Lahontan hydrologic regions are already well covered by cloud seeding projects, except for the Susan River and the Carson River. With the exception of the upper Trinity River watershed, and perhaps the Russian River, there is little new potential in the North Coast Hydrologic Region because limited storage capacity would mean not much extra rainfall could be captured.

There is also potential to increase water production by more effective seeding operations in existing projects. Precipitation enhancement should not be viewed as a remedy for drought, however; cloud seeding opportunities are generally fewer in dry years. They work better in combination with surface or groundwater storage to increase average supplies. In the very wet years, when sponsors already have enough water, cloud seeding operations are usually suspended.

Cloud seeding has advantages over many other strategies of providing water. A project can be developed and implemented relatively quickly without multiyear lead times. In areas where it snows, it could offset some of the loss in snowpack expected from climate change. This may benefit mountain meadows and would delay the fire season in forests. As a resource management strategy, precipitation enhancement would qualify as part of integrated regional water management (IRWM). Seeding opportunities tend to be greater in Northern California than in Southern California because Northern California has more frequent storms and cooler temperatures.

Potential Costs

Costs for cloud seeding generally would be less than $30 per af of water supply each year. State law says that water gained from cloud seeding is treated the same as natural supply in regard to water rights. Southern California projects would be more expensive because of fewer seeding opportunities, but imported supplies are also more expensive there.

It is estimated that about $3 to $5 million is being spent now on yearly operations. Realizing the additional 300,000 to 400,000 af of potential new supply could require an initial investment of around $8 million for planning, reports, and initial equipment, plus around $6 million in annual operations costs. Over the next 25 years, that would add up to about $150 million, which would be nearly $22 per af of water supply.

PLACEHOLDER Photo 11-1 Ground-Based Seeder

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Major Implementation Issues

Reliable Data

No complete and rigorous comprehensive study has been made of all California precipitation enhancement projects. Part of the reason is the natural variability of weather and the difficulty in locating unaffected control basins. Some studies of individual projects have been made in the past years on certain projects, such as the Kings River, which have shown increases in water. A recent evaluation by Dr. Bernard Silverman, published in the journal Atmospheric Research (Silverman 2010), represents the best efforts so far on the longer-running cloud seeding projects and is generally positive in showing results. Aerial seeding, or combination aerial and ground seeding, showed better results than ground seeding alone.

Operational Precision

It is difficult to target seeding materials to the right place in the clouds at the right time. There is an incomplete understanding of how effective operators are in their targeting practices. Chemical tracer experiments have provided support for targeting practices. New seeding agents, and transport and diffusion studies with some of the new atmospheric measuring tools, like some currently being employed by NOAA in hydrometeorological test bed experiments, would be helpful.

Concern over Potential Impacts

Questions about potential unintended impacts from precipitation enhancement have been raised and addressed over the years. Common concerns relate to downwind effects (enhancing precipitation in one area at the expense of those downwind), long-term toxic effects of silver, and added snow removal costs in mountain counties. The U.S. Bureau of Reclamation (USBR) did extensive studies on these issues. The findings were reported in its Project Skywater programmatic environmental impact statement in 1977 and its Sierra Cooperative Pilot Project environmental assessment in 1981. The available evidence does not show that seeding clouds with silver iodide causes a decrease in downwind precipitation; in fact, at times some of the increase of the target area may extend up to 100 miles downwind (Harris 1981). (A seminar specifically on downwind effects at the end of April, 2012 in Las Vegas at the annual meeting of the Weather Modification Association confirmed earlier findings of no loss to downwind areas; often adjacent downwind areas also showed some increase.)

The potential for eventual toxic effects of silver has not been shown to be a problem. Silver and silver compounds have a rather low order of toxicity. According to the USBR, the small amounts used in cloud seeding do not compare to industry emissions of 100 times as much into the atmosphere in many parts of the country or individual exposure from tooth fillings. Watershed concentrations would be extremely low because only small amounts of seeding agent are used. Accumulations in soil, vegetation, and surface runoff have not been large enough to measure above natural background levels. A 2004 study done for Snowy Hydro Limited (Williams and Denholm 2009) in Australia has confirmed the earlier findings described above.

Some silver accumulation testing by PG&E on the Mokelumne River and Lake Almanor watersheds was presented at the 2007 annual meeting of the Weather Modification Association. Both watersheds have been seeded for more than 50 years. Sampling at Upper Blue Lake and Salt Springs Reservoir showed very low to undetectable concentrations in water and sediment. Similar results were found at Lake

Almanor upon testing water, sediment, and fish samples during the 2000-2003 period. Amounts were far below any toxic levels, and there was little to suggest bioaccumulation. Therefore, continued operations should not result in any significant chronic effect on sensitive aquatic organisms.

In regard to snow removal, little direct relationship to increased costs was found for small, incremental changes in storm size, because the amount of equipment and manpower to maintain the roadway is essentially unchanged. In other words, the effort to clear a road of 5.5 inches of snow is practically the same as the effort to clear a road of 5 inches of snow.

All operating projects have suspension criteria designed to stop cloud seeding anytime there is a flood threat. Moreover, the type of storms that produce large floods are naturally quite efficient in processing moisture into rain anyway. In such conditions, seeding is unlikely to make a difference.

Funding

Little federal research funding for weather modification has been available in the past 20 years. The USBR had some funding in 2002 and 2003 in the Weather Damage Mitigation program. Desert Research Institute of Nevada obtained a grant of $318,000 from this source early in 2003 to evaluate its seeding in the eastern Sierra Nevada.

The USBR is also providing some funds to Desert Research Institute for its current Walker River program to augment stream inflow to Walker Lake in Nevada.

Bills introduced in the 110th Congress attempted to reestablish federal support for more weather modification research, some of which would have provided research support on existing operating projects. This legislation was supported by the Western States Water Council, the seven Colorado River basin states, the Colorado River Board of California and others. These bills, Senate Bill 1807 (Hutchison) and House Bill 3445 (Udall) did not pass.

The major research effort in recent years has been funded by the State of Wyoming: an extensive test of cloud seeding in two adjacent mountain regions, the Sierra Madre and the Medicine Bow Mountains. This is a classical randomized statistical experiment in which some storms are seeded and some are not. About 30 cases (testing opportunities) will occur in an average winter season. By the end of 2012, the project had produced 123 cases but needed about 60 more to increase statistical confidence, according to NCAR researchers — which would be at least two more seasons. The Wyoming Legislature in 2012 provided two more years' worth of funding to complete the experiment. Costs are on the order of $1 million per year.

Inadvertent Weather Modification

There is evidence that human activities such as biomass burning, transportation, and agricultural and industrial activities modify local and sometimes regional weather. The effects of aerosols on clouds and precipitation are complex. Studies by Ramanathan, Rosenfeld, Woodley, and others suggest suppressed precipitation formation in affected clouds due to pollution and dust (Ramanathan et al. 2001, Rosenfeld 2000, Rosenfeld and Givati 2006, Rosenfeld and Woodley 2001). Some aerosols can enhance precipitation, and some, especially the very fine aerosols in diesel smoke, can reduce precipitation. Much more research is needed to evaluate the air pollution effects on precipitation processes and the amount of impact, as well as possible effects on cloud seeding programs. It is possible that some of the California cloud seeding projects have offset a potential loss in precipitation from air pollution, which may have obscured a more positive effect from the weather modification projects. Research work in Israel has demonstrated such effects (Givati and Rosenfeld 2009).

Recent research by Scripps and the Pacific Northwest National Laboratory has indicated that dust from western China can increase northern Sierra Nevada west slope precipitation (Ault et al. 2011).

Connections to Other Resource Management Strategies

The precipitation enhancement strategy is strongly connected to these strategies:

- Forest management (see Volume 3, Chapter 23): Much of California's cloud seeding takes place over the forested western side of the Sierra Nevada.
- Watershed management (see Volume 3, Chapter 27): Upper watersheds in the Sierra Nevada are the catchment for enhanced precipitation from cloud seeding.

Recommendations

1. The State should support the continuation of current projects, as well as the development of new projects, and help in seeking research funds for both old and new projects. Operational funding support for new projects may be available through the IRWM program.
2. DWR should collect base data and project sponsor evaluations of existing California precipitation enhancement projects, and projects of other western states; independently analyze them; and perform research on the effectiveness of this technology to supplement water supplies while minimizing negative impacts.
3. DWR should support efforts to investigate the potential to augment Colorado River supply by cloud seeding, in cooperation with the Colorado River Board of California, the other Colorado River basin states, the USBR, and the Metropolitan Water District of Southern California.
4. DWR, in partnership with the USBR, and seeking cooperation from PG&E, should produce an environmental impact report/environmental impact statement on a Pit River-McCloud River project similar to the one proposed several years ago, because this area has one of the best potential yields. This could benefit both the Central Valley Project and the State Water Project (which share in-basin use north of and in the Sacramento-San Joaquin River Delta), and there would appear to be multiple State benefits from augmenting recharge of the huge northeastern California volcanic aquifer.
5. DWR should support research on cloud physics and cloud modeling being done by the NOAA labs and academic institutions. With improvement, these models may become tools to further verify and test the effectiveness of cloud seeding activities.
6. The State should support research on potential new seeding agents, particularly ones that would work at higher temperatures. Climate change may limit the effectiveness of silver iodide, the most commonly used agent, which requires cloud temperatures well below freezing, around -5 ºC, to be effective. (Additionally, the increasing costs of silver are a detriment to some ongoing projects.)
7. DWR should support efforts by California weather modification project sponsors, such as that proposed in 2002-2003 by Santa Barbara County Water Agency, to obtain federal and State research funds for local research experiments built upon their operating cloud seeding projects. In

this regard, DWR recommends that the CEC Electric Program Investment Charge program include research studies on weather modification.

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Figure 11-1 Weather Modification Project Areas in 2011

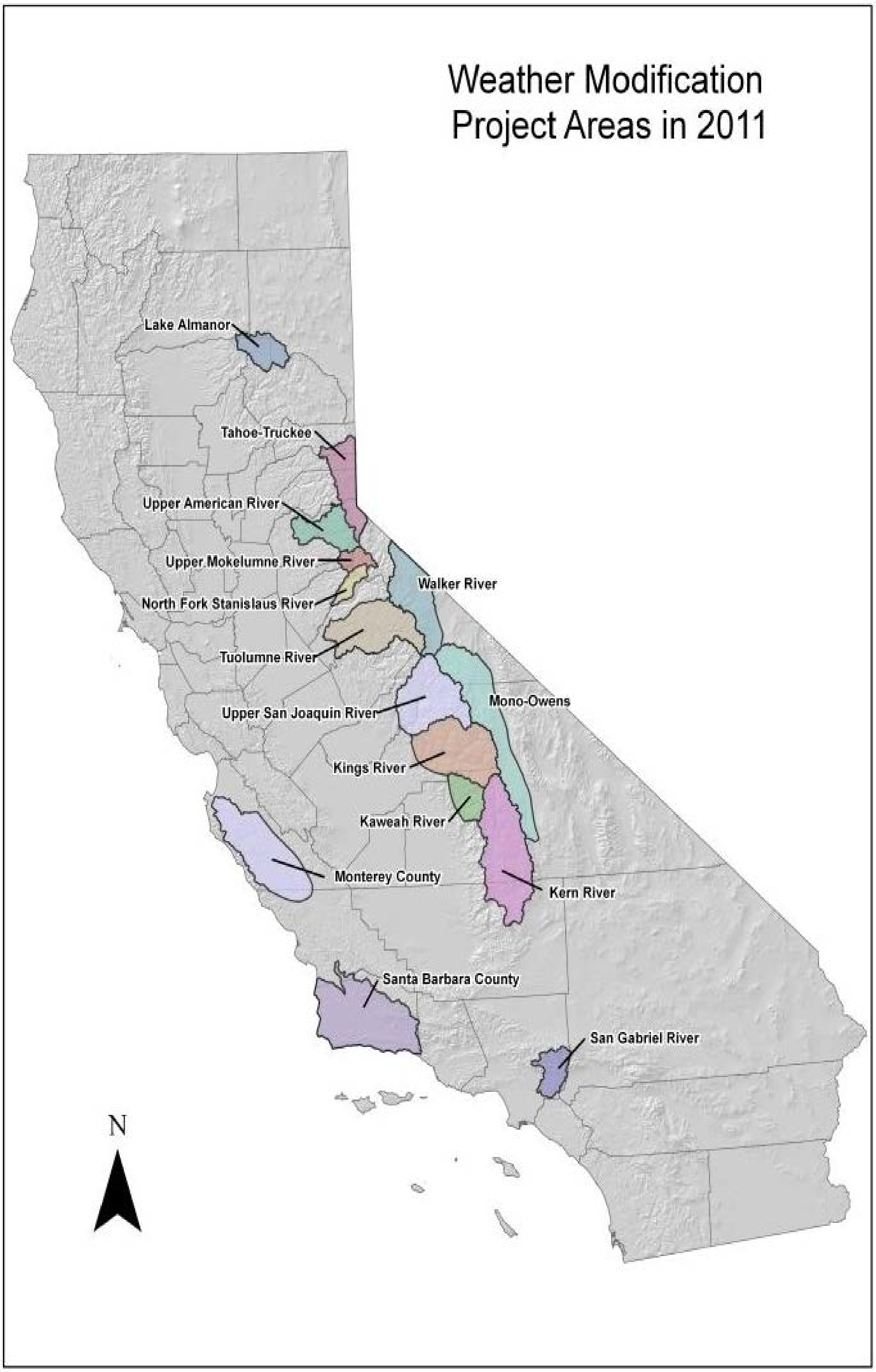

Photo 11-1 Ground-Based Seeder

Photo courtesy of Pacific Gas and Electric Co.